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Measurement of Solar Ultra-violet With Integrating Circuits

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K. B. McCutchon Sept. 1950

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THE UNIVERSITY OF ALBERTA

MEASUREMENT OF SOLAR ULTRA-VIOLET WITH INTEGRATING CIRCUITS

A DISSERTATION

SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

FACULTY OF ARTS AND SCIENCE

by

K. B. McCUTCHON

EDMONTON, ALBERTA,

SEPTEMBER, 1950

Thesis
1950
#63

University of Alberta

Faculty of Arts and Science

Department of Physics

The undersigned hereby certify that they have read and recommended to the School of Graduate Studies for acceptance a thesis entitled "Measurement of Solar Ultra-violet With Integrating Circuits", submitted by K. B. McCutchon, B. A., in partial fulfilment of the requirements for the degree of Master of Science.

Professor

Professor

Professor

September, 1950

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Chapter I: OBJECTIVES

The main objectives of this project were to design and construct some portable integrating circuits capable of giving readings at any time which would represent the ~~total~~ radiation from the sky with wave-lengths of 3150 to 2900 Å incident on a phototube, and to obtain readings with them. Ultra-violet radiation shorter than this is not transmitted by the atmosphere. The apparatus should be simple enough to be tended and used by a layman; it should not require frequent repairs or difficult adjustments.

This wave-length range is known as the biologically effective component of the ultra-violet radiation (abbreviated UVQ) and is of special significance because of its biological effects: it causes tans, sunburns, has bactericidal properties, and stimulates the production of vitamin D in the skin. Haze or ozone in the atmosphere easily obstructs it.

A phototube facing directly south was used for all the measurements taken, because a good percentage of the ultra-violet radiation comes directly from the sun, and usually, as measured with a zirconium phototube, constitutes less than one-thousandth of the total solar radiation (25).

This work was also part of a long-range project (7) to determine the extent of the correlation between the numbers of wild life in Alberta and the total UVQ in a season.

In order to minimize the effect of leakage, considerable attention was given to the recording of broader wave-length ranges. If a close correlation can be established between the UVQ and the ultra-violet to 3650 or 4000 Å or the total radiation,

for a given locality and season, it may ~~be~~ prove easier to take readings of the broader range and from them infer the UVQ from month to month.

Chapter 2: PHOTOTUBES AND FILTERS

A vacuum phototube must be used for linearity of response. A choice theoretically remains between the two-electrode tubes and a multiplier phototube like type IP28 but with a zirconium cathode, not at present available.

As low a voltage should be applied to two-electrode phototubes as the tube characteristics permit for linearity, so that the output will remain more closely proportional to the exciting radiation over long periods of time and the leak will be lower. However, according to Coblentz there is great need for photoelectric cells that do not require stabilization in sensitivity under exposure to sun and weather (2). There is also much variation in sensitivity and insulation between different phototubes of the same type. Of three type 919 tubes tested successively in the photometer (Chapter 3, part c) one registered twice as great a response to a light on uncontrolled line voltage as another and twice the leakage rate of another.

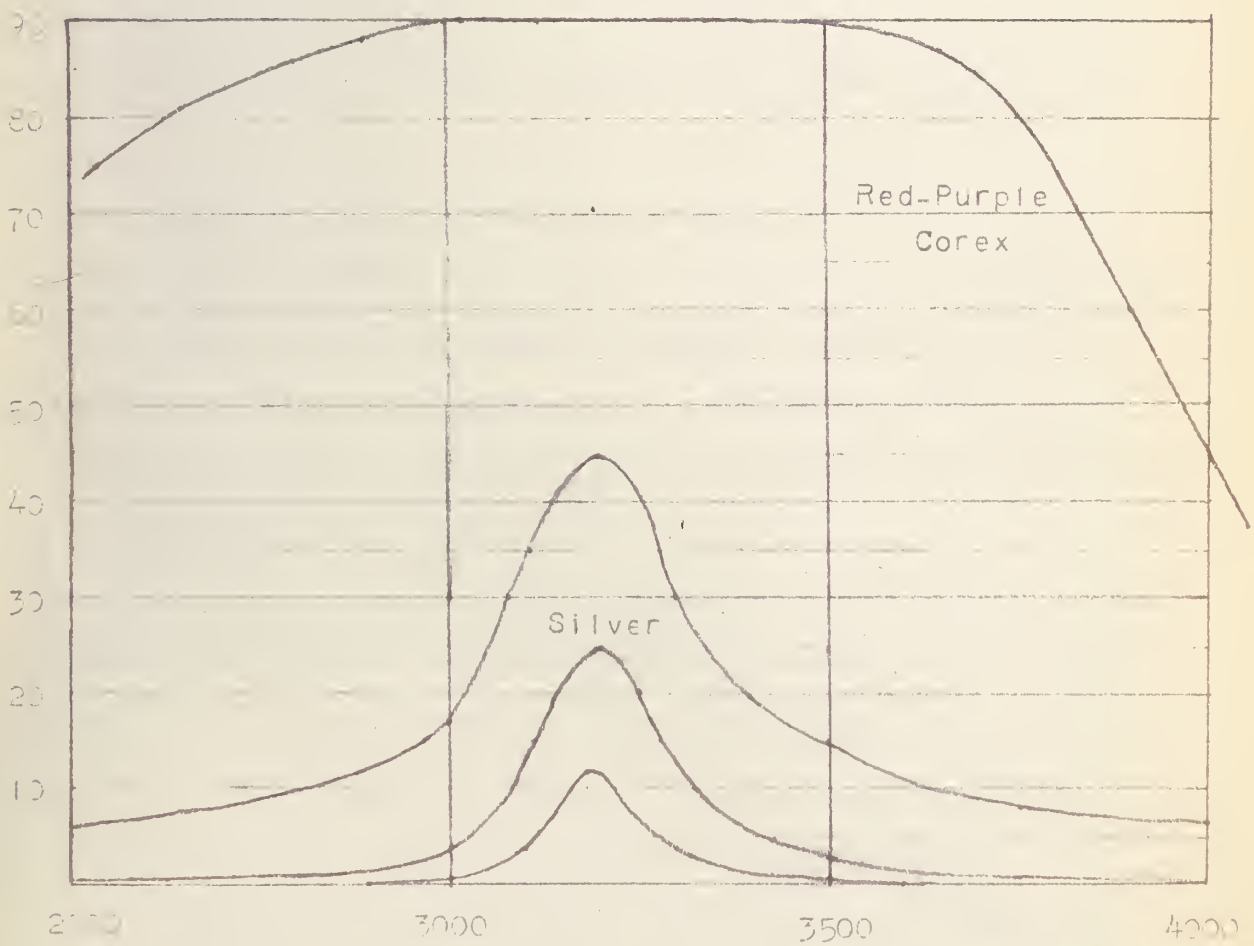
For currents less than about 10^{-10} amp. terminals in a standard base would not be satisfactory because of leakage through the base. Therefore each phototube used in this project had a cap for its cathode, ~~except that each~~ Each type 935 had a cap for what was intended to be its anode but which will be called a cathode because it supplied the photoelectrons as it was used. The type 935 has S-5 response, which is graphed by Zworykin and Ramberg (23) and in the R.C.A. tube manual and outlined in Table I.

The best tube for recording the UVQ without a filter is the Westinghouse WL767, a large tube with a zirconium cathode attached to its cap. (A type with a titanium cathode was formerly

transmitted about half the radiation passed by the coating.

A globular red-purple Corex A filter 1 mm thick obtained from a lamp was also used. Its percentage transmission is given by the ordinates in Fig. 1, from the manufacturer's data, together with the percentage transmission curves given by Luckiesh for two silver films of different thicknesses, separate and combined. The abscissae are measured in angstroms.

Fig. 1. Percentage Transmission of Red-Purple Corex and of Silver Films



Chapter 3: CIRCUITS CONSIDERED

a. Glow Tube Circuit (Fig. 2)

This is the same type of circuit that Coblentz used in Washington, D. C. The photocurrent charges C to the potential necessary to trigger a grid glow tube; when this happens the counter is operated by the plate current and the condenser discharges by grid current. The counter must be of a type that opens its own circuit so that the glow tube will be extinguished immediately.

The counter originally used, which had a resistance of 40 ohms, was such that careful adjustment of both it and the circuit was necessary to prevent it from stalling or chattering. This accounts for the unusual design of the power supply used (Fig. 3).

The 185 v terminal of the power supply was connected to the counter and the 245 v terminal originally to the photoanode.

The voltage regulator tube blinked with each count, for whenever the counter drew current, the voltage regulator tube was extinguished due to lack of current, but only for a negligibly short time.

The voltage regulator tube is provided with "jumper terminals" which have nothing to do with the operation of the tube but which should be connected in series with the line voltage so that the circuit will be turned off automatically whenever the voltage regulator tube is removed from its socket.

It is essential that the glow tube fire at the same grid voltage every time. Two glow tubes, types OA4G and WL712, were

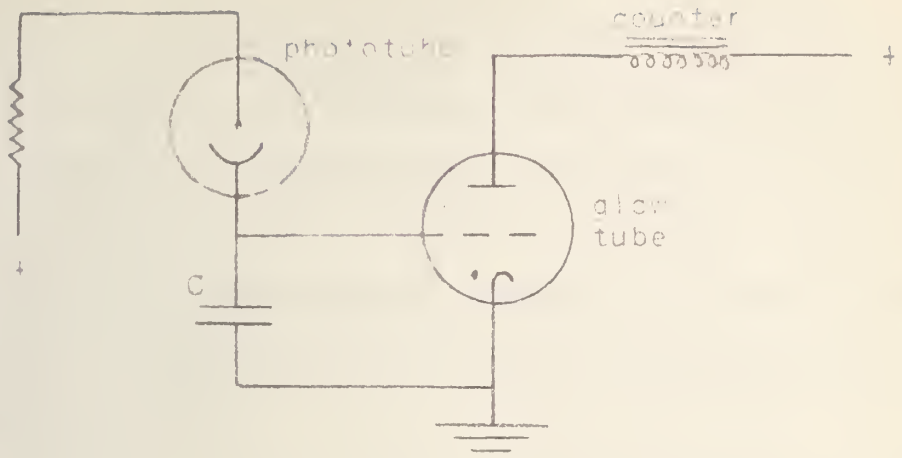


Fig. 2. Glow Tube Circuit

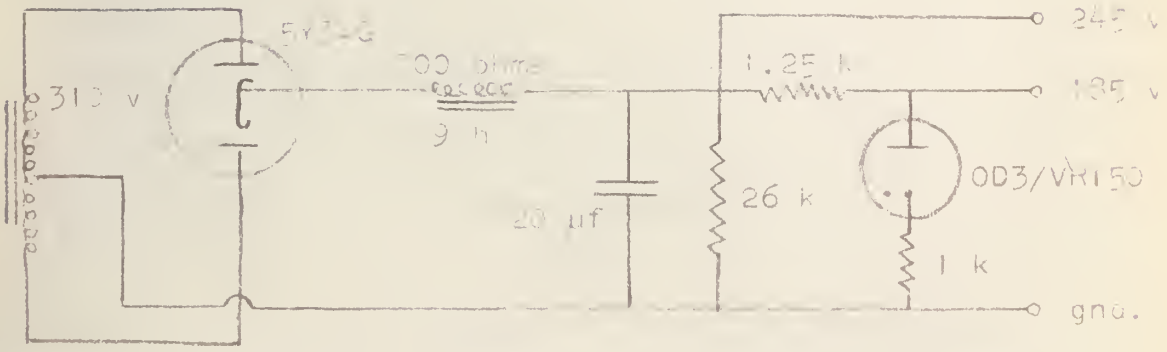


Fig. 3. Power Supply for Glow Tube Integrator

tested by applying a variable power supply voltage to their grids and it was decided to use the WL712, which fires at 125 v with a plate supply of anywhere from 0 to 235 v and perhaps greater.

In Coblentz' apparatus, which was specially constructed, and is described more fully by Zworykin and Ramberg (25), the glow tube, condenser, photoanode and photocathode are sealed in the same glass envelope, which is 8 cm in diameter. He uses more filtering in his power supply, ~~and~~ A relay operates ~~his~~ the counter, which is powered directly with the line voltage and a single-phase rectifier.

The tube sockets for our apparatus were mounted on opposite sides of an ebonite panel so that the tube caps attached to the photocathode and the grid pointed in opposite directions. The caps were connected through a hole in the panel ~~which was~~ plugged with a rather aged amphenol collar which carried a leakage current of .6 micro-microamp. as tested by an electroscope. C was a "glassmike" condenser of value .02 microfarad.

According to Pal (10) there is a theoretical limit to the smallness of the current that can be measured with such a circuit using a gas tube, due to dark current in the gas tube. The theory is as follows, referring to Fig. 4:

$$i_d = i_o f(E) \qquad (a)$$

where the i's represent <u>negative</u> currents at the terminals indicated in the figure and E represents the voltage across C. i_o coulombs are liberated at the cathode per second but their number rises to i_d on reaching the anode, due to ionization.

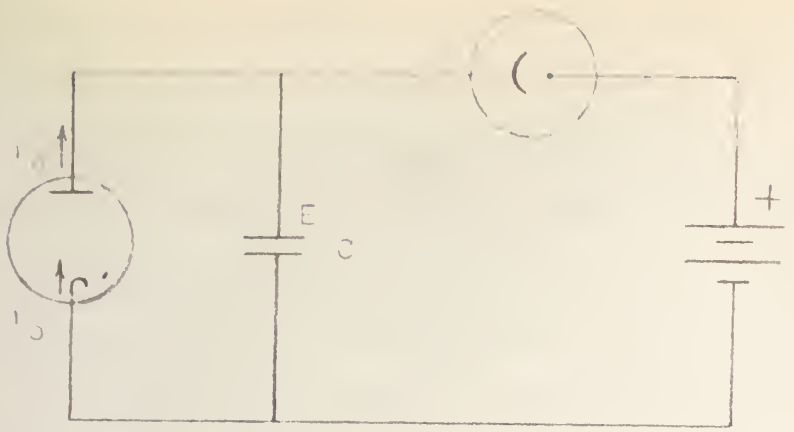


Fig. 4

At the breakdown voltage of the gas tube

$$i_o \, f(E_b) = i_c = \text{constant} \qquad (b)$$

where i_c represents the critical value of i_d, the value for which the tube will always break down.

f(E) begins to increase very rapidly with E when E approaches E_b.

A great increase in i_o would produce a decrease in E_b. i_o fluctuates at random due to cosmic rays, etc. Suppose it is comparatively high and the photocurrent is less than i_c. As E approaches E_b, f(E) and consequently i_d tend to increase greatly and the tube supplies a greater flow of electrons to C and to the photocathode. An equilibrium is therefore reached, with C at, say, 1 v less than E_b, and the gas tube will not fire.

When i_o falls to a comparatively low value E_b is increased by, say, 5 v, on account of (b), thus very greatly reducing f(E) (for E is no longer very close to E_b) and the glow tube current on account of (a). C can then take on a voltage slightly greater than the previous E_b for the tube does not supply as much negative current as before. When another fluctuation in i_o pulls E_b down again sufficiently, the tube will fire.

Thus when the photocurrent is less than i_c discharges will be delayed by a random time, but if the photocurrent is greater than i_c the condenser voltage will be eventually forced up to breakdown value whatever i_o may be, and if it is much greater the interval between discharges will be closely proportional to the photocurrent for the fluctuations in E_b are small compared to E_b. For a glow tube with two zirconium electrodes i_c is about 10^{-10} amp. according to Pal.

The apparatus operated satisfactorily with a type 935 tube but not with a type WL767. The counting rate due to leakage was never found to be regular, even when averaged over a few hours. During August 22-25, when the phototube was silvered, it varied from .304 to .138 per minute. The average leak was about 10^{-10} amp. Current may leak <u>onto</u> the grid as well as off; the <u>net</u> leakage is what is measured, but this depends on the grid voltage, which varies between counts.

In early November the 40-ohm counter could not be made to operate properly so a "Cyclotron Specialties" counter (with a resistance of 5 kilohms) was used instead. Because this does not open its own circuit it had to be connected in series with a switch which would be opened by a 3-milliamp. relay when the tube fired, as shown in Fig. 5. The spring on the switch must be kept tight enough to allow the counter time to operate.

The globular red-purple Corex filter was cemented to a lead base and put over a type 935 tube, designated #1, in the circuit. The integrating capacitance C was made equal to .02 microfarad; each count thus represented 125 x .02 = 2.5 microcoulombs.

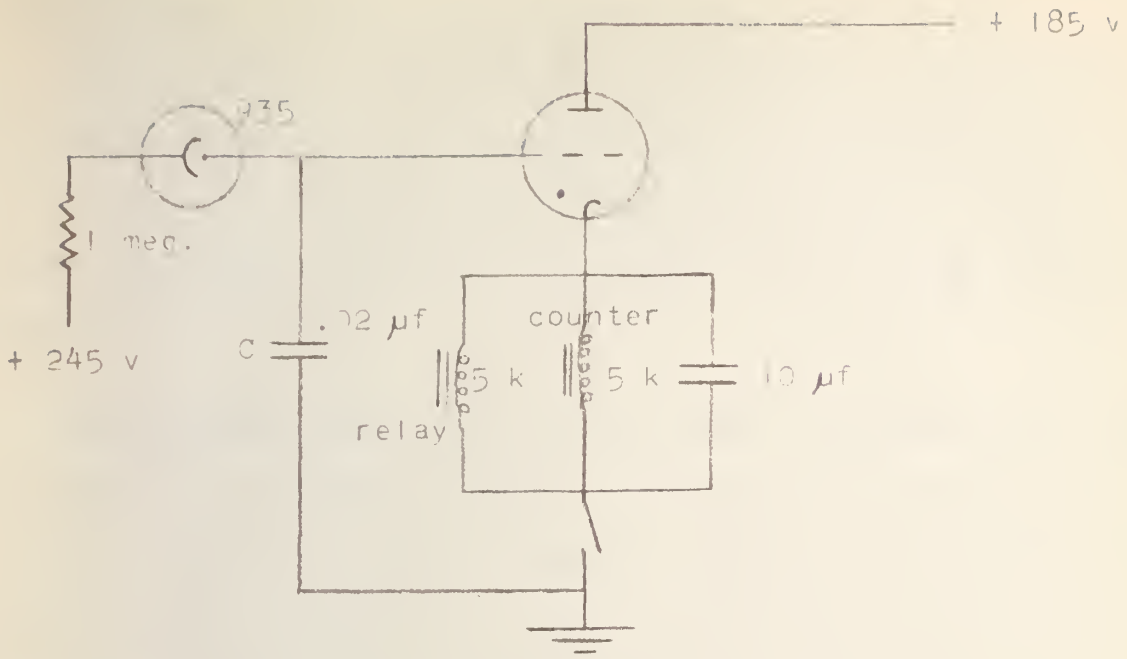


Fig. 5. Glow Tube Circuit as Used

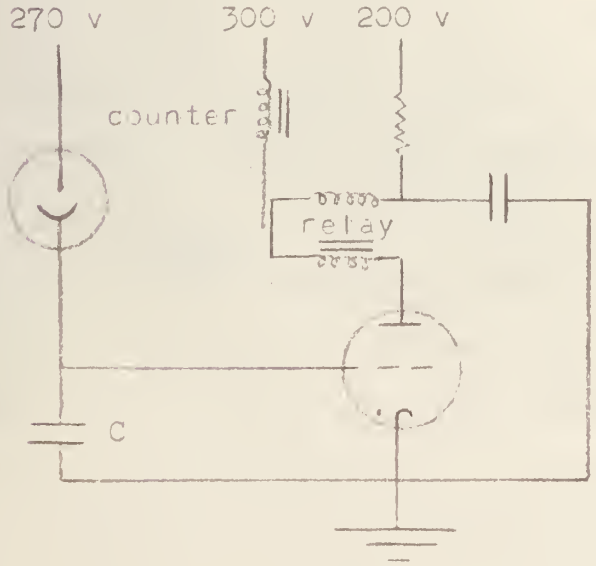


Fig. 6. Westinghouse SM-200

Tested in darkness in early November, when the silver had been cleaned off the phototube, one count required from 30 minutes to 90 minutes, roughly, which seemed very satisfactory.

On November 21 the anode of the phototube was attached to the 185 v terminal, to encourage stable behaviour by the tube, i. e., to avoid rapid ageing. The voltage across it would then reach a minimum of 60 v for each count, still enough for saturation.

Westinghouse puts out a device known as SM-200 which uses an auxiliary condenser to assist operation of a relay, which in turn operates a counter, as shown in Fig. 6. The voltages are taken from the bleeder of a power supply. The auxiliary condenser puts a larger pulse through the relay and tube, after which the plate drops below cutoff if the resistance shown above the relay is great enough.

b. Trigger Circuit

This is a one-shot multivibrator type of circuit and was adapted from a trigger circuit given by Regener (11). Such a circuit operates on the same integrating principle as the preceding apparatus but requires two pentodes, possibly under the same envelope, instead of a glow tube. It would be advantageous because it ~~would~~ should remove the dark-current effect, making possible the measurement of currents much less than 10^{-10} amp. ~~and because~~ Also the firing voltage might remain constant longer.

Consider the circuit of Fig. 7. Normally the tube V_2 is conducting. When C is charged up to cutoff, the circuit triggers:

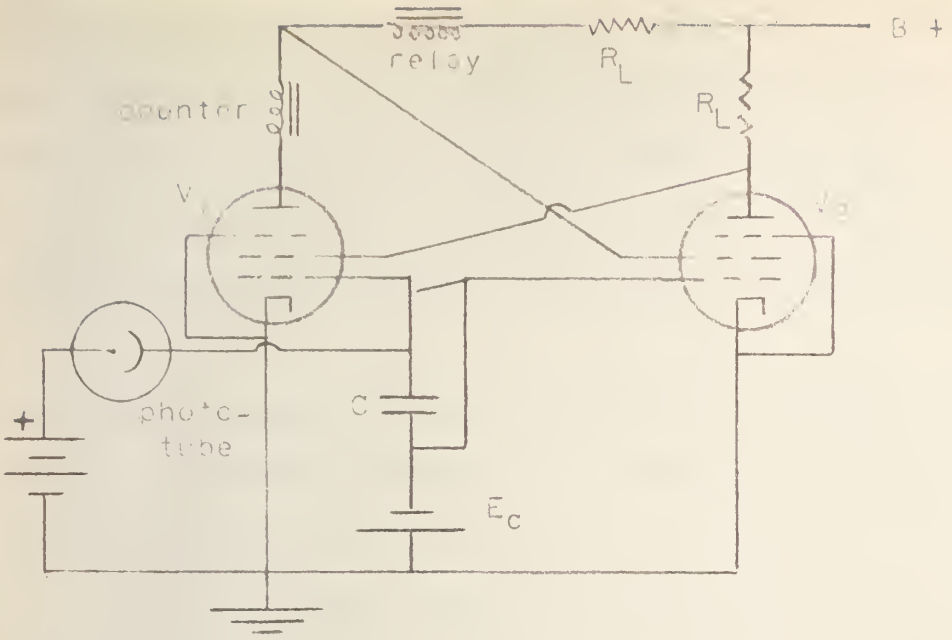


Fig. 7. Trigger Circuit. The pentodes are type 6K6.
R_L = 47 k: E_{bb} = 350 v: E_c = -45 v: C = .01 microfarad

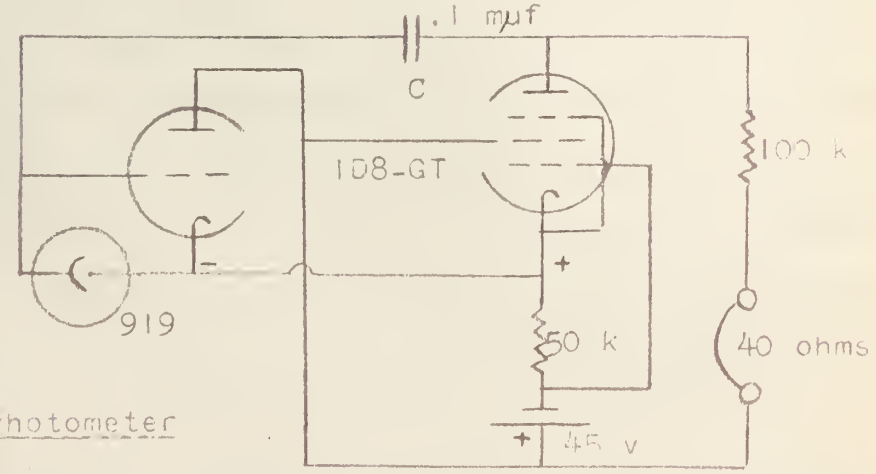


Fig. 8. Photometer

V_1 conducts and screen 2 consequently drops in potential, stopping V_2 from conducting. While the relay closes the switch, allowing C to discharge, the counter operates and opens the plate circuit, which at once increases the voltage on screen 2 and so causes V_2 to fire. It was found experimentally that the 3-milliamp. relay would operate satisfactorily with the circuit shown, but the 40-ohm counter would not. No more was done with this.

To avoid leakage at grid 1 due to the switch, the circuit should be redesigned using at least one grid cap and a "glassmike" condenser C between plate 2 and grid 1 (instead of where shown in Fig. 7). This condenser would discharge with grid current. If possible a well-regulated power supply should be used instead of batteries. (See pp. 43-44 for a further discussion of this circuit.)

c. Photometer

This circuit (Fig. 8) was originally designed as an exposure meter for dark room use with a type 919 phototube (12). The other tube, type 1D8-GT, has a cap for its triode grid. As constructed, both tubes plus a flashlight battery for the 1D8 filament were put inside a small chassis and the 45 v battery and earphones externally connected. Originally the positive side of the 45 v battery was connected to the chassis, so that the earphones would be safer to handle. In an attempt to reduce leakage, ceresin wax was brushed around the condenser C and the type 1D8 tube, but it did not seem to make any difference (see pp. 44-45).

The photometer is another one-shot multivibrator and possesses the same advantages as the previously described "trigger

circuit." Normally the triode grid is below cutoff and the pentode is conducting; the voltage drop across the cathode resistor keeps the triode from conducting for a while. Due to photocurrent the triode grid gradually climbs in potential. When it reaches cutoff the triode begins to conduct; this increases the bias on the pentode control grid (on account of the cathode resistor) and consequently reduces the pentode plate current, producing a positive pulse at the pentode plate which is fed back through the condenser C to the triode grid. (Conduction through the cathode resistor also reduces the potential of the pentode screen grid and of the triode plate but the effect of the latter reduction on the triode plate current is overcome by the effect of the grid increase.)

The feedback through the condenser increases the potential of the triode grid so greatly that it discharges through the filament, whereupon a flow of electrons from the condenser biases it beyond cutoff again. (The positive pulse on the pentode plate has induced and bound a negative charge onto the other side of the condenser, leaving the triode grid more positive; after the first discharge between grid and filament the triode plate current drops, the pentode plate current increases, some of the negative charge on the other side of the condenser is released, and electrons flow to the triode grid, making it more negative.) This cycle results in a very sharp rectangular pulse with a pulse width of about 1/600 second. The current change in the earphones produces a clearly audible "click".

Increasing the load resistance does not have much effect

on the pentode plate current (this is a characteristic of pentodes) and therefore it increases the d. c. drop across the load, increasing the pulses and enabling them to induce a greater charge onto the condenser until grid current flows. The net effect is a decrease in pulsing rate. This effect was noted experimentally.

Also, increasing the plate supply voltage (by using a variac, rectifier, and filter) was found experimentally to increase the d. c. drop across the load sufficiently to increase the period between pulses by about 2.6% per volt in the 40 to 50 v range.

When a microammeter was put in series with the photoanode and a load resistance of 570 kilohms and a 45 v battery were used it was found that a counting rate of 4.17 pulses per second corresponded to a photocurrent of 2.5 milli-microamps.; i. e., .60 milli-microcoulomb would give 1 pulse.

$$\Delta V = Q/C = .6/.1 = 6 \text{ v}$$

Therefore between pulses the triode grid ranged from -8 v to -2 v approximately.

Constancy of cutoff voltage, an important matter, was checked. The apparatus was stimulated with a lamp powered by a constant output transformer. Times required for ten counts were taken, using a stop watch, and averaged. The mean of seven averages taken at different times was found to be 24.6 seconds while the average deviation of the averages from this was 1.1 seconds or 4.3%. The range of averages was from 23.0 to 26.4; the terms of these had average deviations of .10 and .09 respectively. It was also concluded that although the periods varied slowly (the greatest of four variations was 2.46 seconds in 105 minutes) they increased with time at a random

rate as long as the apparatus was not disconnected at any time.

Similar behaviour was observed when a filtered rectifier powered by another constant output transformer was used instead of the 45 v battery.

Before the pulses can operate a counter they must be amplified. Further data on this apparatus is given on pp. 21-26.

d. Van der Tweel Integrator (16)

This apparatus consists of a one-shot multivibrator coupled to a pulse lengthener which operates a counter. The tube which is triggered must have high mutual conductance at low anode currents and of course high insulation; Van der Tweel recommends a Philips type CF50. It would be necessary to obtain the European type tubes or to experiment with modifications of the circuit.

Once constructed this circuit would have the same general limitations and advantages as the photometer. It was decided instead to construct an amplifier for the photometer (Chapter 4).

e. Weston Integrator (6)

This uses a movable coil in a permanent magnet and a trigger circuit as described in (11). The input current must be at least 15 microamps. through a load of less than 1200 ohms; with a zirconium phototube this would necessitate a d. c. current amplifier. Furthermore, the list price of the integrator is $575, so its use is not suggested.

f. Lindemann Electrometer Circuit

Constructed in 1934 and rearranged more conveniently in the fall of 1949 by Dr. E. H. Gowan, the Lindemann electrometer

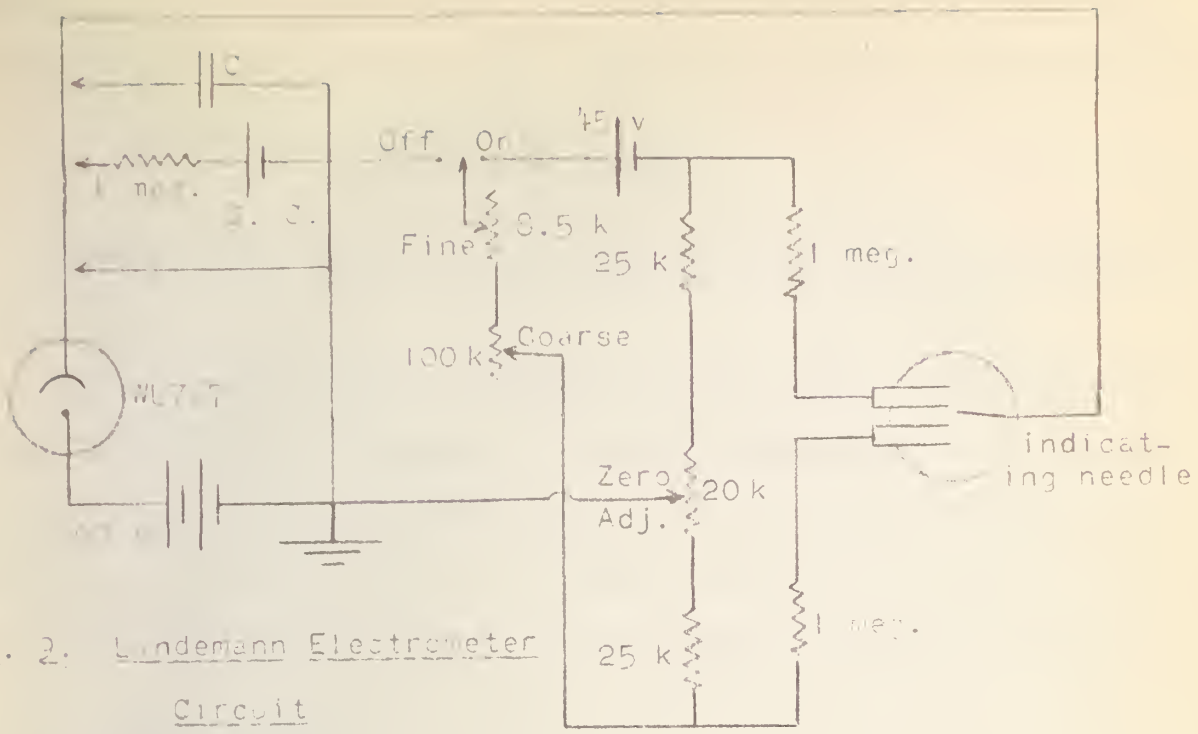


Fig. 2. Lindemann Electrometer Circuit

control circuit (Fig. 9) resembles that described by Grimmett (8). It is contained in a wooden box 13 x 8 x 11 inches and uses a type WL767 phototube and a "glassmike" condenser, with Lucite insulation for the photocathode and indicating needle.

To make the preliminary adjustments the apparatus is switched on, closing the 45 v battery circuit. The indicating needle is kept grounded and is set at the zero mark on the scale of the microscope eyepiece by the zero control; then it is "degrounded" and the standard cell applied to it. By means of the coarse and fine controls the indicating needle is set at a standard mark on the scale. It is well to let the apparatus sit for a while and then repeat these adjustments.

For taking measurements, the standard cell is disconnected and a capacitance C attached to the indicating needle. The

number of milli-microcoulombs liberated will be proportional to the change in the reading, thus (where C is in milli-microfarads):

$$\int_{t_1}^{t_2} i \, dt = Q = C \, \Delta V$$

Readings were taken often enough so that ΔV did not exceed 5 v.

The overnight leakage and dark current with voltage applied to the WL767 was undetectable. The only apparent disadvantages of this apparatus are the delicacy of the indicating part, the difficulty of readjusting if it should be allowed to drift too far, and a tendency to pick up extra charge in thundery weather.

g. Electrolysis

An apparatus for electrolysis of water may be used as an integrating circuit by leading a photocurrent into it and reading the volume of hydrogen liberated in a capillary tube. The calculations following show that although a zirconium tube would not give off enough current in a year for a measurable reading without amplification, a filtered 935 should give enough for accurate daily readings, so the apparatus has been constructed.

1 microcoulomb liberates $10^{13}/3.2$ molecules of H_2. These occupy 1.12×10^{-7} cc at standard temperature and pressure. 1 microamp. in 10^7 seconds (116 days) would liberate 1.12 cc. Thus 1 microamp. would liberate about .01 cc per day at S.T.P.

If the capillary tube has a cross-section of 0.2 sq mm this amounts to 50 mm of gas in one day at S.T.P., which would be enough for a sufficiently accurate reading.

But $\int i \, dt$ over one day corresponds to a maximum current

~~over~~ for only about 6 hours.

Therefore a maximum photocurrent of 4 microamps. will be necessary at S.T.P.--but even this corresponds to an inadequate current for dull days.

h. Miscellaneous

At the Edmonton airport a photocurrent from a type WL773 (thorium cathode) tube was led into a Micromax Ballistic recorder to produce curves which were mechanically integrated later.

Considerable difficulty with leakage was experienced when a zirconium phototube was used in the photometer. It would be possible to eliminate the effect of leakage by putting a mechanical "light-chopper" in front of the phototube, operating at around 30 cuts per second, and amplifying and rectifying the a. c. output. This is not recommended for this project because it would be incompatible with the simplicity desired.

Chapter 4: PULSE AMPLIFIER FOR PHOTOMETER

In order to enable substitution of a counter for the earphones it is necessary to amplify the pulse across the load resistor of the photometer (Table 2).

Table 2

1D8 Load	100 k	175 k	570 k
Pulse	4½ v	7 v	11 v
D. C. Voltage Drop	15 v	17½ v	26 v

Several available amplifiers were tried but none would operate a "Cyclotron Specialties" counter directly. It was decided to construct an amplifier, incorporating a power supply for it in the same chassis.

The second stage of the amplifier constructed (Fig. 10) is a cathode-follower for power amplification and was adapted from the last stage of a Geiger counter. The first stage is a cathode-feedback amplifier. The heaters were tied to the 6V6 cathode, which is at somewhere between 14 and 26 v, depending on the plate supply. Since the counter had a resistance of only 5 kilohms the resistor in parallel with it was not essential. Taking the photometer output across the cathode bias resistor (whose d. c. drop was 6 v) as well as the load worked very well and gave practically the same pulse.

The negative end of the 1D8 filament and both chassis were grounded because sometimes otherwise the apparatus would vibrate too much due to the ungrounded line voltage and the counter would not operate. Perhaps using a lower grid resistance for the 6V6 would have prevented such eventualities but grounding was found

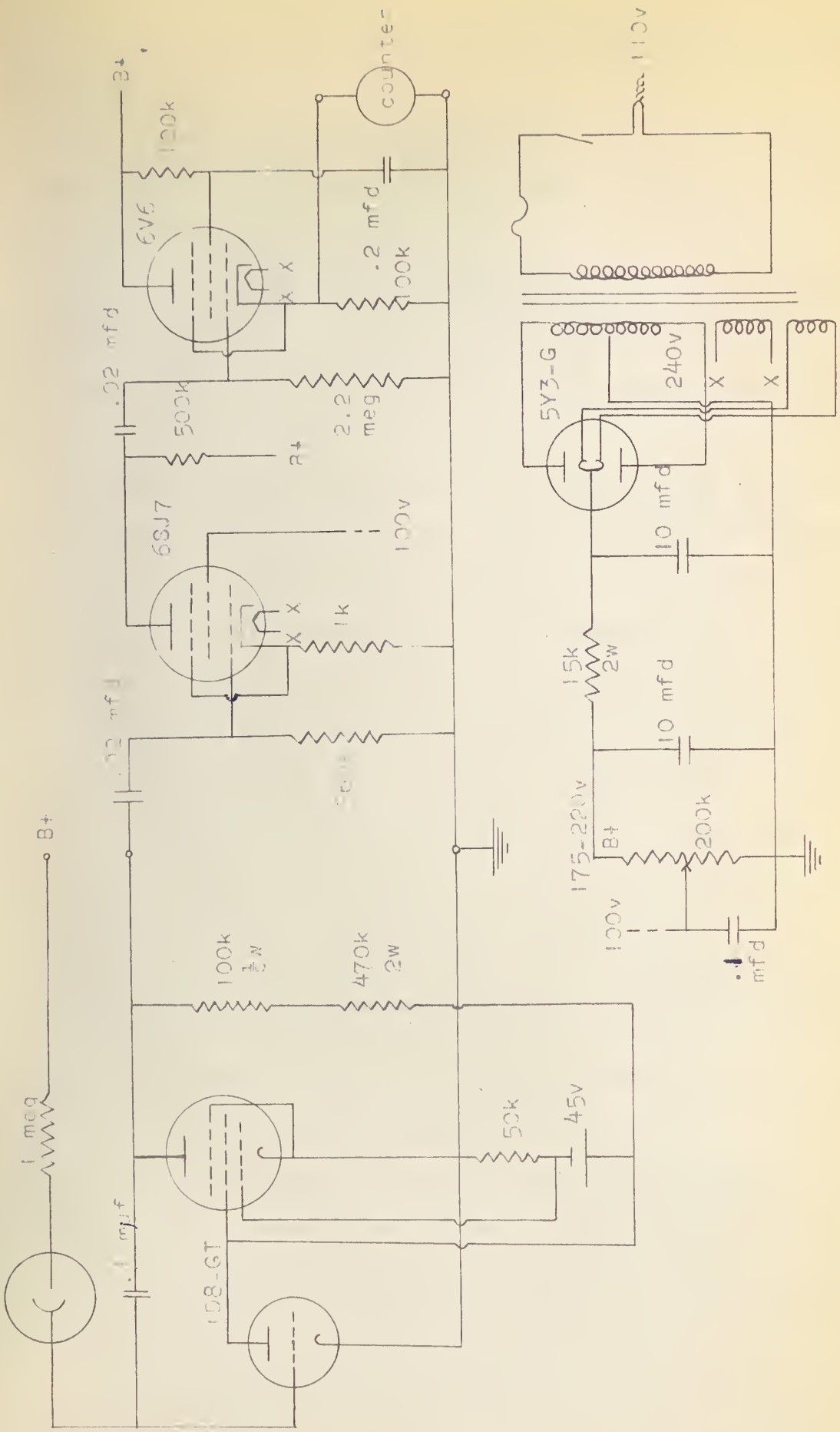


Fig. 10. Photometer With Pulse Amplifier

quite satisfactory. The calculated ripple of the power supply was about 25 millivolts.

After November 24 the photoanode was led to the 6SJ7 screen, which was closer to the recommended voltage of the phototube, instead of to the plate supply.

The effect of interlead capacitance was found to be negligible (as Roberts states it should be) by temporarily connecting a .02 microfarad condenser across the output leads of the photometer.

The pulse is badly distorted by the first stage of R-C coupling, which differentiates the lowest frequency component. The time constant of this stage is RC = 1100k x .02 microfarad = .022 second. For differentiation the reactance must be much greater than the resistance, i. e., $1/f \gg 2\pi RC = .138$ second, where f represents the repetition frequency of the pulses. For March 21, when f was greatest, $1/f = 9 \times 3600/30,740 = 1.05$ seconds (p. 31). The current in the coupling circuit then closely equals $C \frac{de}{dt}$ where e represents the input voltage. Therefore the output voltage will closely equal $RC \frac{de}{dt}$.

Analysis of the pulse into sinusoidal components, however, will give many waves with amplitudes nearly as great which do not satisfy the condition and will not be differentiated but will be shifted in phase. ~~differently~~.

If feedback is reduced by using a by-pass condenser for the 6SJ7 cathode further frequency-dependent phase shifting and distortion result, and the counter will not work if such a condenser is put in.

Chapter 5: OBSERVATIONS

Table 3

Circuit	Phototube	Filter	Upper Limit
Glow Tube	935 #1 reversed	1 mm red-purple Corex A	about 4000 Å
Photometer	935 #2 reversed	thinly silvered Corex D	in the visible (see p. 5)
Lind. El.	WL767	none	3150 Å
Thorium	WL773	none	3675 Å

a. Photometer Observations

From October 24 to December 16 almost daily readings were taken with the photometer using a zirconium phototube (WL767). A socket for this tube had been installed in the small chassis, which together with the 45 v battery was put on a metal ledge outside a window of a third floor room in the Arts Building to take the readings. Shielded wire with amphenol insulation was used for the photocathode lead, the shield being grounded.

The 1.5 v flashlight battery could not power the ID8 filament--which draws 0.1 amp.--for the long periods desired so a larger type battery was substituted on November 2. Two of these in parallel were used from November 26 on.

From October 29 to November 4 leakage produced an average of .16 counts per minute, with an average deviation of about .013 per minute, measured inside with the window open. The readings listed for November 3-7 (p. 27) have been corrected for this average leakage. Each count for this period represents .60 millimicrocoulomb. Later the apparent leakage was found to vary considerably, often dropping to values below .06 counts per minute (one reading of 2 counts in 60 minutes was obtained), and the

photocurrent dropped to little more than this variation, so the other photometer readings taken with this tube are not included in this thesis.

The phototube was occasionally turned to face the sun during November 3-5 but was kept facing directly south afterwards, as were the phototubes of the other circuits all the time.

By January 17 the circuit was adapted to take a type 935 phototube, designated #2, with terminals reversed, inside a silvered Corex D cylinder. These were mounted vertically on a wooden block with a metal base, which was placed outside the window to take the readings, the rest of the apparatus remaining inside. Originally polyethylene-insulated wire was used for the photocathode, leading back to an amphenol shielded-wire stem. This often gave trouble, gaining a count when approached and losing a count when receded from (due to induction, because the insulated section is more negative than ground) and producing a count only about once in 10 minutes unless adjusted somehow. Therefore on January 27 amphenol shielded wire was installed all the way from the photometer circuit to the photocathode, the shield being grounded just outside the chassis. This arrangement showed no faults. An integrating capacitance C ten times as great, 1.0 milli-microfarad, was installed. Each count from then on represents 6.0 milli-microcoulombs.

From February 8 to 13 the apparatus would not work, although it would count once each time the 1D8 filament circuit was closed and nothing was found wrong with the circuit. The data is inconclusive but perhaps this ~~inoperativeness~~ failure was due to the great change in temperature which the phototube had to undergo periodically

because it was kept inside each night, which may have resulted in deposition of invisible dirt on the phototube when it fogged up. After the phototube was cleaned with alcohol the circuit worked. A few days later the glow tube circuit also stopped for no apparent reason and would not work with a different 935 tube either. Before the glow tube was cleaned the globular filter was found broken so no further work was done with this apparatus. Abnormally high voltage drops (about 13 v) were recorded across the photoanode resistors of both circuits during their inoperative periods.

b. Other Information

The glow tube circuit, each of whose counts represents 2500 milli-microcoulombs, was operated with a vertical phototube from the same window as the photometer. ~~and~~ This was the only other circuit subjected to such extreme temperature changes (often around 100° F in the winter) and ~~refusing~~ it refused to work in the same manner. Care was taken never to subject either of these circuits to rain.

The Arts Building is situated so that in early morning and late afternoon the sun was blocked by other buildings during winter. No readings are recorded for those times. The power plant sometimes exuded a thick smoke which usually drifted east and tended to obscure the sun; this happened on February 16, March 8, 9, 13, and to some extent on March 10 and 11.

The thorium phototube, with its axis tilted 37° from vertical, was operated 3 miles north of the Arts Building. The resulting curves were integrated with a planimeter at an arbitrary setting, but some of these measurements were difficult to take due to irregular behaviour of the Micromax recorder. The

worst of these are marked "poor" and were not used in the statistical analysis.

The Lindemann electrometer, whose readings are given in milli-microcoulombs, was used $\frac{3}{4}$ mile south of the Arts Building. Its zirconium tube was the one originally used with the photometer.

The column in Table 4 headed "Thorium" gives the relative areas corresponding to the Mountain Standard times listed on the left, for purposes of comparison with the photometer and glow tube readings. The column headed "All Day Thorium" gives the relative areas for each whole day listed on the left, for comparison with the Lindemann electrometer readings (L. E.). Whenever the latter do not correspond to the whole period of sunlight the corresponding area is listed in brackets and is of course used in the statistical calculations unless the word "poor" appears in the same line.

c. Tabulation of Readings: Table 4

		Photometer, WL767	Thorium
Nov 3	11:57-15:45	198	19.8
Nov 4	10:51-16:08	140	23.2
Nov 5	11:22-13:15	120	11.0
Nov 7	10:07-15:50	135	19.4
		Glow Tube, 935 #1	
Nov 9	2:24-16:12	396	2.7
Nov 10	12:05-15:27	170	2.1
Nov 14	10:00-15:53	2840	17.9
Nov 15	12:27-15:57	1820	9.5
Nov 16	9:04-16:06	1670	13.5 (poor)
Nov 17	13:34-16:15	--	2.0

		Glow Tube, 935 #1	Thorium
Nov 18	10:03-15:46	2120	12.5
Nov 19	10:18-14:06	1114	12.9
		(185 v on photoanode)	
Nov 21	9:30-15:03	2950	16.0
Nov 23	9:30-15:36	3097	16.5
Nov 24	10:14-15:42	1761	11.0
Nov 25	9:30-13:15	274	3.5
Nov 26	10:03-13:05	390	3.5
Nov 28	13:46-16:04	434	10.5
Nov 29	9:55-14:53	2489	23 (poor)
Nov 30	11:47-15:18	1483	18 (poor)
Dec 1	10:24-14:48	326	4 (poor)
Dec 2	9:51-15:01	1847	10.6
Dec 3	10:13-13:31	455	3.9
Dec 6	14:24-15:24	126	0.6
Dec 7	10:26-13:18	857	3.7
Dec 8	10:01-15:44	1922	10.5
Dec 9	10:07-15:16	2203	11.2
Dec 10	11:27-14:17	409	3.7
Dec 14	10:23-15:29	717	6.8
Dec 16	10:36-15:39	1507	10.5
Jan 4	10:31-15:21	2334	12.1
Jan 11	12:22-15:21	1286	8.3
Jan 12	11:58-15:51	1129	8.3
Jan 13	10:08-15:32	2390	13.5
Jan 16	10:06-15:24	2723	--
Jan 17	10:08-15:29	3310	17.4
(Jan 18	10:52-15:32	1979	14.0)

		Glow Tube 935 #1	Photometer 935 #2	Thorium	All Day Thorium	L. E.
Jan 18	10:52-15:32	1979	16,180	14.0		
Jan 19	10:04-15:53	2439		18.5		
Jan 23	10:31-15:42	1664		16 (poor)		
Jan 24	10:07-15:15	2898	31,400	24 (poor)		
Jan 25	13:39-15:50	1466	13,165	8.5	27.5	
Jan 26	10:00-15:42	4462	42,707	23.0	25.0	
Jan 27	10:16-15:45	4413	lead and C changed	25.7		
Jan 28					29.0(27.9)	129
Jan 30	10:19-19:30	3456	4586	20.9	22.4	85
Jan 31					24.5	33.4
Feb 1	10:17-16:16	3330	5730	25.5	29.9	71.2
Feb 2	9:52-16:14	5020	5982	36.7	38.8	167
Feb 3	10:32-15:21	3508	4914	25.2	30.1(29.9)	170
Feb 4	10:01-16:17	3471	5308	29.3	32.3(32.2)	140
Feb 5					23.2	71
Feb 6	10:13-16:18	2801	4740	40.7(poor)	46.6	84.2
Feb 7	10:00-16:07	4000	5760	27.8	30.7	155
Feb 8	10:13-16:09	1413		13.1	14.9	34
Feb 9	12:47-16:05	2721		16.8	35.3	166
Feb 10	10:10-16:00	4500		33.3	40.4	198
Feb 11					26.5	81
Feb 12					42.5	288
Feb 13	10:09-16:12	2920		26.4	30.0	140
Feb 14	10:10-16:16	3586		33.8	37.4	226
		935 #2	935 #1			
Feb 15	10:02-16:14	--	7397	37.3	40.8	304
Feb 16	10:02-16:19	--	3542	25.0	27.0	235
Feb 16	12:10-16:19	3595	2287	16.0	27.0	235

		Glow Tube 935 #2	Photometer 935 #1	Thorium	All Day Thorium	L. E.
Feb 17	9:51-15:55	5182	3048	24.0	26.2	103
Feb 18					39.4	150
Feb 19					35.2	278
Feb 20	12:12-16:24	9854	5427	29.4	48.4	335
Feb 21	10:04-16:27	4615	3500	19.8	23.0	86
		935 #1	935 #2			
Feb 22	11:00-17:04	1651	4,071	22.9	29.1	72
Feb 23	9:57-16:20		16,870	55.9	60.4	435
Feb 24	11:05-16:17		7,230	26.1	34.8	142
Feb 25	10:35-16:32		13,638	42.4	49.1	415
Feb 26					29.8	156
Feb 27					42.9	122
Feb 28	10:57-16:28		8,300	33.7	44.9	162
Mar 1	10:37-16:33		4,895	64 (poor)	75 (74.7)	614
Mar 2	8:53-16:39		11,443	39 (poor)	42	248
Mar 3					46.8(46.7)	385
Mar 4					77.2(77.0)	801
Mar 5					70.2	640
Mar 6	11:51-16:07		2,954	13.0	23.6(23.4)	91.5
Mar 7	10:05-17:58		8,450	41.4	45.4	165
Mar 8	10:10-15:03		14,270	65.4(poor)	78.2(77.3)	321
Mar 9	9:55-15:08		15,181	69.8	90.5	546
Mar 10	10:35-17:47		17,205	62.8	74.4(73.9)	477
Mar 11	12:11-16:58		9,250	39.8	66.9	436
Mar 12					82.2	699
Mar 13	10:04-16:02		8,133	32.9	42.8(42.0)	208
Mar 14	9:56-16:14		13,195	54.4	61.3	475
Mar 15	10:09-16:03		7,745	37.2	48.3(48.2)	177

		Photometer 935 #2	Thorium	All Day Thorium	L. E.
Mar 16	9:53-15:53	16,785	74.9	89.4	838
Mar 17	10:07-15:59	12,105	53.0	71.3 (68.0)	548
Mar 18	10:02-16:58	19,845	84.4	97.0 (95.5)	957
Mar 19				80.3 (79.3)	1104
Mar 20	10:03-16:40	20,520	87.2	108.0(105.9)	1055
Mar 21	7:55-16:55	30,740	95.5	100.3	1050
Mar 22	9:05-15:46	8,800	57.4	78.1 (77.5)	320
Mar 23	8:55-15:58	18,107	77.0	88.0 (87.9)	1135
Mar 24				64.4 (62.6)	385
Mar 25				68.3 (63.6)	245
Mar 26				34.7	272
Mar 28	7:53-11:26	2,200	20.1	87.3	692
Mar 29				94.6	1300
Mar 30				62.7	500
Mar 31				79.4	980
Apr 2	7:00-19:30			103.0	1610
Apr 3	8:05-19:30			96.5	1350
Apr 4	7:00-18:30			107.9	1780
Apr 5	8:15-19:00			110.7	2280
Apr 9	9:45-20:00			38.9	262
Apr 10	7:15-19:30			94.3	790
Apr 11	7:30-19:20			120.7	1930
Apr 12	7:55-19:40			65.5	1020
Apr 13	8:45-19:30			64.5	1000
Apr 14	6:55-19:00			110.7	2060
Apr 15	8:00-17:50			46.5	740
Apr 16	5:50-20:00			104.2	2020
Apr 18	6:45-18:15			108.2	1870

		Thorium	L. E.
Apr 19	6:15-19:30	133.7	2730
Apr 20	7:50-19:30	115.4	3070
Apr 21	8:15-19:30	109.0	1950
Apr 22	8:15-19:45	49.7	770
Apr 23	8:05-20:00	62.8	820
Apr 24	7:00-20:00	119.5	2400
Apr 25	7:00-19:15	65.8	280
Apr 26	7:05-19:30	119.0	2220
Apr 27	7:25-19:40	115.2	1970
Apr 28	8:00-20:00	53.6	950
Apr 29	5:10-20:00	92.1	1690
Apr 30	5:10-20:00	123.6	2400
May 1	5:16-19:30	134.8	3070
May 2	5:00-20:00	118.3	2480
May 3	5:00-19:45	129.6	2410
May 4	5:00-19:30	134.4	2580
May 6	8:15-20:00	62.6	870
May 7	5:00-16:10	106.4	1900
May 15	5:00-17:30	106.4	2330
May 16	8:15-20:00	131.8	2740
May 18	7:05-16:20	104.3	1450
May 19	9:35-18:45	109.8	2170
May 20	8:45-20:00	119.2	2300
May 21	5:00-19:30	120.8	2390
May 22	8:30-19:00	83.5	1660
May 23	6:05-15:55	80.6	1310
May 25	7:35-18:35	96.5	2680
May 26	8:00-19:00	139.5	4330

		Thorium	L. E.
May 27	6:05-19:00	95.2	1395
May 28	6:55-22:00	134.2	1850
May 30	8:15-14:40	111.0	2020
May 31	8:15-20:30	127.5	2360
Jun 1	8:15-19:00	92.8	1570
Jun 2	5:30-18:30	155.1	3100
Jun 3	7:00-17:30	123.0	2620
Jun 4	7:30-18:30	54.7	1700
Jun 5	8:30-13:30	42.0	695
Jun 6	9:45-19:45	113.3	2900
Jun 7	4:50-20:00	121.5	3260
Jun 8	Dawn-19:30	156.8	2640
Jun 9	Dawn-16:15	149.5	3390
Jun 12	Dawn-19:00	134.9	3720
Jun 13	Dawn-14:00	79.0	1085
Jun 14	Dawn-19:30	59.9	1115
Jun 15	12:55-20:30	35.1	1310
Jun 19	Dawn-20:00	186.1	6560
Jun 21	8:15-18:45	107.8	3170
Jun 22	7:50-18:05	100.7	1310
Jun 23	8:30-19:30	113.9	1350
Jun 24	8:05-21:00	139.2	990
Jun 25	Dawn-21:00	149.4	1420
Jun 26	9:10-15:15	81.2	1595
Jun 27	9:40-20:30	129.3	3180
Jun 28	Dawn-20:30	147.4	4420
Jun 29	Dawn-14:15	100.5	2810
Jun 30	Dawn-14:15	115.2	3950

For a few days a new zirconium tube was used with the photometer and readings taken with the axis of the tube tilted at an angle of 37° from vertical, to catch more radiation from the sun. These readings are listed in Table 5 and are not corrected for leakage.

Table 5

Apr 24	11:22-17:03	175
Apr 25	9:05-17:23	47
Apr 26	9:53-16:42	89
Apr 27	11:37-17:04	56
Apr 29	9:45-17:08	60
May 1	10:04-16:31	106
May 2	9:57-16:56	74
May 3	9:10-17:02	94
May 4	9:37-16:25	77

On May 5 the leakage of this was tested with the window closed, resulting in 5 counts in 358 minutes, or an average of 1 count in 72 minutes. The results of various photometer apparent leakage measurements are given in micro-microamps. in Table 6.

Table 6

Oct 29-Nov 4	1.6
Dec 6	0.33
May 5	1.4

These are in line with the leakage given by Roberts (13).

Chapter 6: ANALYSIS OF OBSERVATIONS

The linear correlation coefficient between two variables X and Y, which represents their degree of linear relationship when the scatter diagram for the sample gives a cluster of points comprising a roughly elliptical shape, is given by

$$r = \frac{\mathrm{cov}(X,Y)}{s_x s_y} = \frac{S(XY) - S(X)S(Y)/n}{(n-1)s_x s_y} \qquad (17)$$

$$(n-1)s_x^2 = S(X^2) - S^2(X)/n \qquad (18)$$

where $S(X)$ means the sum of all the X's, $S(XY)$ means the sum of all the products of corresponding readings, s_x represents the standard deviation of the X-readings, and n the number of pairs of readings.

Using a working origin affects neither the correlation coefficient nor the standard deviations, but it makes the calculations easier. Thus comparing thorium readings $(X_1 + 30)$ with Lindemann electrometer readings $(Y_1 + 500)$ for Jan. 28, 30, 31, Feb. 1-5, 7-28, Mar. 3-7, 9-26, 28-31, we obtain:

$S(X_1) = 1223\frac{1}{2}$ $\qquad$ $S(Y_1) = -6869$

$S(X_1^2) = 59,850$ $\qquad$ $S(Y_1^2) = 6,957,000$

$n = 57$ $\qquad$ $S(X_1Y_1) = 264,100$

$$r = \frac{394,000}{\sqrt{33,660 \times 6,129,000}} = .868$$

Considering the measurements to have been selected from a large number of pairs of measurements, the 95% confidence limits of the actual correlation coefficient of the larger population are .78 and .92. These are obtained from a graph quoted by Wilks (19) together with the values of r and n.

Within the range which has been used one may predict a

Lindemann electrometer reading from a thorium reading on the basis of the method of least squares by the formula

$$\frac{Y_1 - \bar{Y}_1}{X_1 - \bar{X}_1} = r\frac{s_y}{s_x} = \frac{S(X_1Y_1) - S(X_1)S(Y_1)/n}{S(X_1^2) - S^2(X_1)/n} \qquad (20)$$

$$= \text{regression coefficient of } Y_1 \text{ on } X_1$$

where $\bar{X}_1 = S(X_1)/n$ and $\bar{Y}_1 = S(Y_1)/n$. This gives

$$\frac{Y_1 - 120.6}{X_1 - 21.46} = \frac{394,000}{33,660} = 11.71$$

A measure of the accuracy of predictions made with this formula is given by the standard error of estimate, s_e, where

$$s_e^2 = \frac{n-1}{n-2}\, s_y^2(1-r^2) = 27,500 \qquad (21)$$

Therefore s_e = 166 milli-microcoulombs. We may expect 67.5% of the predictions made by this formula to be within this much of what the true Lindemann electrometer reading would be, assuming the relationship between Y_1 and X_1 to be linear, the variance of Y_1 to be independent of X_1, and the errors in Y_1 to be normally distributed.

Comparing thorium readings (X_2 + 30) with Lindemann electrometer readings (Y_2 + 500) for all days in April, May, and June for which pairs of readings are listed, we obtain:

$S(X_2) = 5196$ $\qquad$ $S(Y_2) = 113,300$

$S(X_2^2) = 459,000$ $\qquad$ $S(Y_2^2) = 231,800,000$

$n = 69$ $\qquad$ $S(X_2Y_2) = 9,896,000$

$$r = \frac{1,364,000}{\sqrt{67,700 \times 45,800,000}} = .775$$

Comparing glow tube circuit readings (G_T + 1000) with thorium readings (T_G + 10.0) for all days for which pairs of readings are listed except Nov. 16, 29, 30, Dec. 1, Jan. 23, 24, Feb. 6, we obtain:

$S(T_G) = 211.1$ $\quad S(G_T) = 49,190$

$S(T_G^2) = 4750$ $\quad S(G_T^2) = 132,400,000$

$n = 43$ $\quad S(T_G G_T) = 725,900$

$$r = \frac{484,400}{\sqrt{3713 \times 76,100,000}} = .911$$

Comparing photometer readings (P_T + 5000) with thorium readings (T_P + 20.0) for all days after Jan. 28 for which pairs of readings are listed except Feb. 6, Feb. 15-21, Mar. 1, 2, 8 we obtain:

$S(T_P) = 713.1$ $\quad S(P_T) = 158,600$

$S(T_P^2) = 32,430$ $\quad S(P_T^2) = 2,138,000,000$

$n = 27$ $\quad S(P_T T_P) = 7,974,000$

$$r = \frac{3,785,000}{\sqrt{13,600 \times 1,207,000,000}} = .934$$

Comparing glow tube readings (G_P + 3000) with photometer readings (P_G + 5000) for Jan. 30 to Feb. 4, Feb. 6, 7, 22 gives:

$S(G_P) = 3237$ $\quad S(P_G) = 1091$

$S(G_P^2) = 7,736,000$ $\quad S(P_G^2) = 3,279,000$

$n = 8$ $\quad S(G_P P_G) = 4,687,000$

$$r = \frac{4,246,000}{\sqrt{6,426,000 \times 3,130,000}} = .947$$

Table 7

	Glow Tube, Photometer	Glow Tube, Thorium	Photom., Thorium	Thorium, L. E.*
Correlation Coefficient	.947	.911	.934	.868
95% Confidence Limits	.72, .98	.82, .95	.85, .97	.78, .92
Distance Between Circuits	0	3 mi.	3 mi.	$3\frac{3}{4}$ mi.

*The April-May-June correlation of .775 (95% confidence limits .66 and .85) is omitted from this table.

To predict photometer readings from glow tube circuit readings the formula is

$$\frac{P - 136.4}{G - 405} = \frac{4,246,000}{6,426,000} = .660$$

Knowing how many milli-microcoulombs correspond to each count for each circuit, this suggests that for minimum error we should assume each additional milli-microcoulomb produced by the 935 #2 tube filtered with the silvered Corex cylinder corresponds to an additional .660 x 2500/6 = 275 milli-microcoulombs in the 935 #1 tube filtered with the red-purple Corex globe, within the range in which readings were taken. Nevertheless the four readings taken Feb. 16-21 show that tube #2 was more productive of photocurrent than tube #1 under similar circumstances; therefore the high ratio can be attributed to the filters (see p. 5).

It is a principle of statistics that such prediction formulas cannot be trusted outside the range in which the readings were taken, but if the responses of the circuits compared were linear in relationship down to zero intensity we should expect the constant terms in the formulas to be quite small. Taking Lindemann electrometer readings predicted from thorium readings as an example, we are concerned here with the accuracy of the predicted value of Y, called Y', rather than that of Y itself.

The standard error squared of the mean predicted Y, $\bar{Y}$, equals

$$s_{\bar{y}}^2 = \frac{s_e^2}{n} \qquad (22)$$

The standard error squared of $\frac{Y - \bar{Y}}{X - \bar{X}}$ is given by

$$s_b^2 = \frac{s_e^2}{S(x^2) - S^2(x)/n} \qquad (3)$$

Therefore the standard error squared of Y' due to sampling errors in the regression line is given by

$$s_{y'}^2 = s_{\bar{y}}^2 + s_b^2(X-\bar{X})^2$$

But we are concerned with $s_{y'}$ where X = -30, which is given by

$$s_{y'}^2 = s_e^2 \left(\frac{1}{n} + \frac{(\bar{X} + 30)^2}{S(x^2) - S^2(x)/n} \right)$$

The actual deviation of $\hat{Y}'$ at X = -30 is given by the constant term in the prediction formula. One may divide this by $s_{y'}$ and refer to Fig. A or Table A given by Ezekiel (4), using n-1 instead of n, to find the proportion of samples which would give a larger constant term than the one obtained (assuming strictly linear relationships), which is given in the last column of Table 8. In this table the working origins are dropped; actual readings of counts are to be substituted.

Table 8

To Predict	Formula	s_e^2	$s_{y'}$	Proportion
P from G	P = .66 G + 2890	53,700	322	about .001
G " P	G = 1.36 P - 3580	110,200	971	.01
G " T	G = 130 T + 199	315,000	162	.22
T " G	T = .00636 G + 1.26	14.6	1.10	.25
T " P	T = .00314 P + 12.3	69.3	3.05	about .003
P " T	P = 278 T - 2040	6.15×10^6	1100	.07
Y_1 " X_1	$Y_1 = 11.7\ X_1 + 18$	27,500	51.5	about .7
Y_2 " X_2	$Y_2 = 20.1\ X_2 + 22$	273,500	221	nearly 1.00

When the intensity of illumination is reduced by clouds or haze the proportion of shorter ultra-violet radiation which is transmitted is known to be reduced much more than is the

proportion of the longer ultra-violet. Because of this the linear formulas in Table 8 cannot be expected to hold over a wide range of intensities when phototube-filter combinations significantly different in their relative responses to various wave-lengths are involved; i. e., most of the regression lines ought to be curved at the bottom. This probably explains to a great extent the presence of the constant terms in the formulas and the great difference between the slopes given by the last two formulas. The standard errors of these slopes as computed by the last equation on p. 38 are only .90 and .20 respectively.

In the first two formulas the constant terms are much too great to be attributed to leakage, which indicates that the glow tube readings gave more emphasis to the UVQ than did the photometer readings. This is more or less confirmed by the third and fourth formulas, which indicate roughly similar spectral selectivities in the 935 #1 with its red-purple Corex filter and the thorium tube, but is contradicted, unfortunately, by the fifth and sixth formulas. The contradiction between the third and fourth formulas has a low probability of occurrence which is nevertheless greater than .22 x .25 because the regression lines are bound to be different unless r = 1.

The high linear correlations obtained from the glow tube, photometer, and thorium tube circuits may be contrasted with a table published by Coblentz (1) listing the UVQ and the <u>total</u> solar and sky radiation (Q) for each month of the year, averaged over eight years. This table shows the UVQ to be closely proportional to Q^2 when the readings are averaged over a month as in the table.

The ineffectiveness of the smoke in blocking radiation to the photometer (p. 26) is shown by the photometer readings given in Table 9, in which the sixth formula is used.

Table 9

	Recorded	Predicted
Mar 9	15,181	17,380
Mar 10	17,205	15,500
Mar 11	9,250	9,040
Mar 13	8,133	7,110
Totals:	49,769	49,000

Chapter 7: CONCLUSIONS

All circuits performed quite satisfactorily when they were in operating condition, aside from small deviations which might be due to differing spectral selectivities, varying cutoff voltage (p. 16), and differing cloud conditions over the circuits (but not to the smoke mentioned on p. 26). Good linear correlations between various ranges of ultra-violet radiation, as shown in Tables 7 and 3 on pp. 37 and 24, have been established but it may be necessary to use thicker filters to obtain such close linear correlations between the 935's and a WL767.

Zirconium tube (WL767) readings may be expected to be subnormal compared to other readings during winter because of air absorption and during spring because of increased amounts of ozone in the upper atmosphere; however, the increase in the slope of the prediction line from 11.7 in February-March to 20.1 in April-May-June shows that any increase in average ozone concentration between these periods had a comparatively minor influence. From February to March the slope increased by about half, which is not significant since the 95% confidence limits overlap.

Statistical conclusions about the spectral selectivities have been given on p. 40. The importance of variations in zirconium phototubes is evident from, for example, observations by Fabry and Buisson showing that the midsummer intensity at 2898 $\mathring{A}$ is only about one-millionth of that at 3143 $\mathring{A}$ under the most favorable conditions, at sea-level (5).

To encourage uninterrupted operation of the circuits probably none of them should be subjected to temperature changes great enough to cause the phototube to fog.

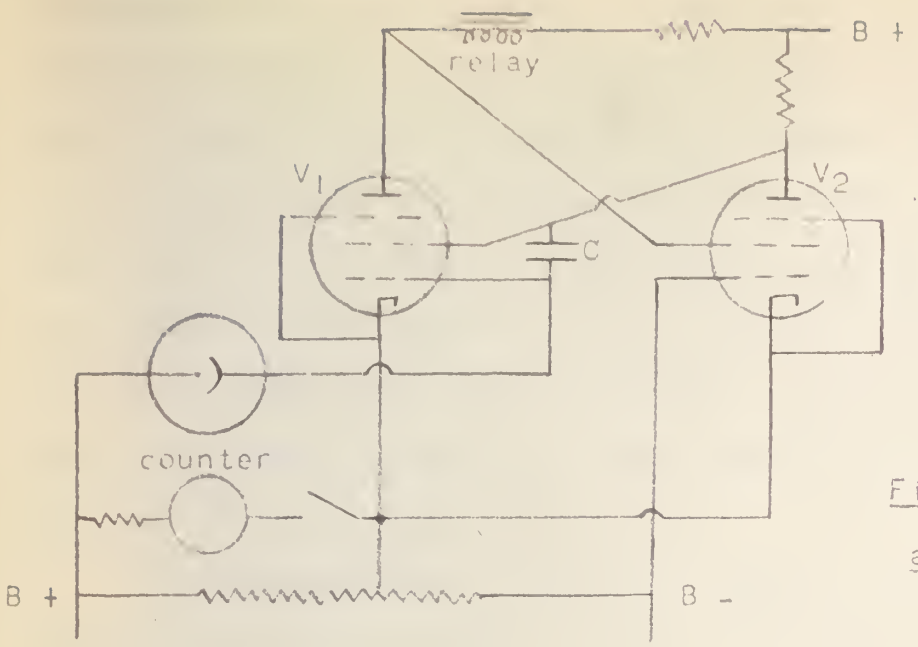


Fig. 11. Design For a Trigger Circuit

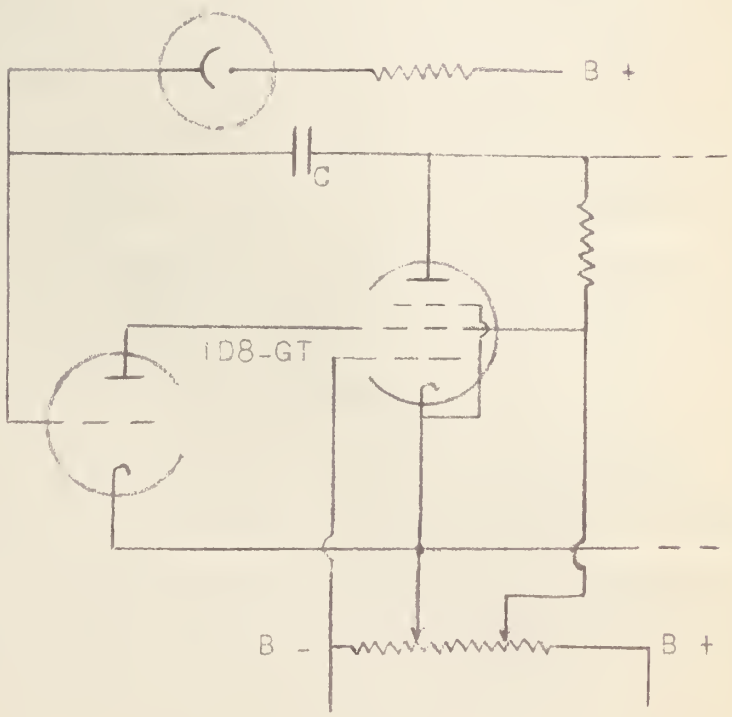


Fig. 12. Design For a Photometer Without Batteries

The photometer and the trigger circuit (as well as the Lindemann electrometer) have an advantage over the glow tube circuit in being able to integrate currents smaller than 10^{-10} amp. and the trigger circuit has the further advantage of not requiring a pulse amplifier although further experimentation would be needed to obtain a satisfactory design. If the "Cyclotron Specialties" counter will not operate in the trigger circuit even with the switch arrangement shown in Fig. 4 (p. 11) the relay could be used to close a separate circuit with a counter in it as shown in Fig. 11.

In the photometer a shielded lead to the photocathode is necessary if the phototube is not in the same chassis with the type 1D8 tube, and perhaps even if it is. The firing voltages of different 1D8's should be examined as described on p. 16. The 1D8 filament should be run from the power supply (to make the $1\frac{1}{2}$ v batteries unnecessary). If this is done the power supply should be regulated with voltage regulator tubes, whose "jumper terminals" should be connected in series with the line. Also a lower grid resistance may be used with the 6V6. It might be possible to do away with the 45 v battery by some such arrangement as shown in Fig. 12, or an independent regulated power supply may be substituted. The latter would require an additional transformer if the photometer is to be grounded.

A condenser of the same type as used in the photometer was tested in the Lindemann electrometer and no overnight leakage was detected. The insulation of the 1D8 might be improved by dipping it in melted natural ceresin, first warming it in order

that its temperature be not changed too suddenly (13). With ceresin (which may have been imitation) brushed on, the insulation was not noticeably increased and was inadequate for use with a zirconium tube in the winter but was sufficient with the filtered type 935 tube. Dust tends to stick to this wax and therefore the ID8 should be well protected from dust if it is waxed. Insulation decreases with increasing humidity and the wax is used principally for combatting this effect.

Chapter 8: REFERENCES

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